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EFFECT OF STATIC MAGNETIC FIELD ON SOME PARAMETERS OF GERMINATION BARLEY SEEDS USING TWO MATHEMATICAL MODELS

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ABSTRACT : In this study, a laboratory experiment has been carried out to study the effect of a static magnetic field (SMF) of 125 mT on barley seeds. For evaluation of these experiments, some germination parameters have been recorded. Also, two mathematical models, Logistic (Log) and Gompertz (Gom) functions were performed in each treatment, for comparative analyses of parameters of the cumulative germination curves and mean square error (MSE). The best values have been found at treatment MG3 in FGP (95%), S.G (5.66 seed day^{-1}), MGT (3.61 days), GRI (28.31% day^{-1}), and GI (84). The highest value of asymptotic germination barley seeds was recorded in the Gom equation (96.78%) at the exposure time of 6 h (MG3). As well as, the best maximum germination rates reached 2.07% h^{-1} with Gom functions at MG2, while the highest value of the germination percentage of the inflection point has been reported in the Log function for 47.21 at MG3. For the fit growth curve, the results have demonstrated that the Log function has given the lowest values in MSE in all MG exposure times compared with the Gom function. So, the Log function has shown a more fitting in all MG treatments, as compared with the Gom function.

Key words : Static magnetic field, Logistic function, Gompertz function, inflection point, barley.

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INTRODUCTION

The magnetic field treatment method can be considered one of the foremost pre-sowing seed treatments, which has a less harmful influence on the environment (Araujo *et al*, 2016). The static magnetic field (SMF) originates either from a constant magnet (magnetic material as a ring or cylindrical, or square stripe magnet) or from a direct current-fed electromagnet. Whereas, an alternating magnetic field is a time-varying electromagnetic field that has fed by the alternating current across a solenoid. Several researchers have acknowledged the positive effects of SMF on plant germinating seeds. For example, Lazim and Marwan (2019) have reported an improvement in some germination parameters of wheat seeds exposure to SMF at the induction of 125 mT. Similar positive results of germination seeds have shown for sorghum (Nurbaity *et al*, 2019; Lazim and Nasur, 2017); maize (Vashisth and Josh, 2016); wheat (Sen and Alikamanoglu, 2016); Soybean (Lewandowska *et al*, 2019; Kataria *et al*, 2015); Lettuce (Mousavizadeh *et al*, 2013); lentil (Asgharipour and Omrani, 2011); sunflower (Vashisth and Nagarajan, 2010) and barley (Lazim and Marwan, 2020a; Martinez *et al*, 2000). Some authors have used statistical and mathematical functions to analyze seed germination curves, such as Logistic function (Yin *et al*, 2020; Lazim and Marwan, 2020b); Generalized logistic function (Szparaga and Czerwinska, 2017); Gompertz function (Gupta *et al*, 2012); Richards function (Ukalska and Jastrzêbowski, 2019) and Weibull function (Oraki *et al*, 2011). Furthermore, some authors employed mathematical functions during the study of germination kinetics after prior physical seed treatments. In the analysis of the germination kinetics curve, it was recorded a positive effect of the magnetic treatment of sunflower seeds using the logistic equation by Matwiejczuk *et al* (2012). Muszynski *et al* (2009) also studied the Gompertz germination curve in the presence of low-frequency magnetic fields on wheat seedling germination and growth. This work aims at two mains goals; the first purpose is to investigate the effects of different periods of static magnetic field exposure time on some of the germination parameters of barley seeds. The second aim is to select an appropriate model function (Logistic or Gompertz) that matches the seed germination curves of the barley plant after exposure to a magnetic field.

MATERIALS AND METHODS

Commercial barley seeds (Arivat) cultivar selected for uniform size and shape, were first to soak for 2 hours in distilled water. Subsequently, the seeds have been divided into four groups, each group having 60 seeds in three replicates. Then seeds have been exposed to a static magnetic field (SMF) of 125 mT with different exposure periods of 0 h (MG0) as a control, 2 h (MG1), 4 h (MG2), and 6 h (MG3). Following treatments, all treated seeds have been planted in Petri dishes (100 mm in diameter) with an absorbent paper towel moistened with distilled water under laboratory conditions. A final count number of germinated seeds were recorded every 12 hours after two days from the start of the experiment. And then, the percentage of germinated seeds were recorded until the 8th day since there have no more germinated seeds present. The seed calculates into account germinated when the seed radical it had been a minimum of 2 mm. Some germination parameters were recorded in order to evaluate the effect of SMF treatments on barley seeds:

The total number of seedlings at the end of the test after the seventh day has followed by the final percentage of germination seeds (FGP %), which has calculated as follows:

FGP %= (Number of germination seeds after 7 days) / (Total number of seeds planted) ×100 (1)

The speed germination (S.G) has calculated as described in the Association of Official Seed Analysts (AOSA, 1983) as follows:

S.G. = (N.of germinated seed) /(Days of 1st count) + ... + (N. of germinated seed) /(Days of final count) (seed day^{-1}) (2)

The Mean Germination Time (MGT) has calculated according to the following formula of Ellis and Roberts (1981):

$$MGT= (\Sigma nD) /n \text{ (day)} \quad (3)$$

Where, n: is the number of seeds, which germinated agrees with the day (D) observation (not the accumulated number) and (D) is the number of days counted from the beginning of germination.

Germination Rate Index (GRI) has been calculated according to the following formula of Esechie (1994):

$$GRI = G_1/1+G_2/2+G_3/3+ ... +G_n/n \text{ (\%day}^{-1}) \quad (4)$$

Where, G1, G2 …Gn are the germination percentage × 100 at the first, second and subsequent days after sowing until the 9th day; 1,2… and n are the days of first, second… and final count, respectively.

Germination Index (GI) was calculated according to the following formula of kader (2005):

$$GI = (10\times n1) + (9\times n2) + ... +(1\times n10) \quad (5)$$

Where, n1, n2. . . n9 are the number of germinated seeds on the first, second and subsequent days until the 10th day; 10, 9... and 1 are the number of germinated seeds on the first, second and subsequent days, respectively.

The Logistic and Gompertz models have been used to analyses the cumulative germination curves of barley seeds overtime after the impact of SMF. Moreover, a comparison between the two models was performed in each magnetic treatment. The functions of Logistic and Gompertz are given are in the following equations (6) and (7), respectively.

Logistic model:

$$Y= C/[1+B \times \exp (-A \times T)] \quad (6)$$

Gompertz model:

$$Y= C \exp [-B \times \exp (-A \times T)] \quad (7)$$

Where, Y (t) represents the cumulative proportion of seeds that have germinated at any given time, denoted as a percentage. While, (t) means the germination time, expressed as the time growing in hours after sowing. C: is the asymptotic value of Y, which represents the maximum cumulative percentage of germinated seeds after a long time, while B and A are model parameters. To statistically describe the germination process, the following parameters have been calculated: the time needed to get the inflection point of the logistic and Gompertz curves is: T_{inf}= (lnB)/A, the germination percentage at the point of inflection of Logistic and Gompertz curves (G_{inf}) at which growth have been reached to 1/2C and 0.368*C, respectively, Vmax is the maximal rate of germination for point of inflection of logistic (V_{max} = (C.A) /4) and Gompertz (V_{max} = (C_*A) /e) curves. The best-fitting growth curve was done based on the mean square error (MSE) and the coefficient of determination (R^2). The statistical analyses have been used in the experimental study, according to a completely randomized design, with three replications each Petri dish represents one replicate. Also, the analyses of the results have done using SPSS 20.

RESULTS AND DISCUSSION

Germination parameters

The results are summarized in Table 1, which show that the magnetically treated seeds had a significant effect on all germination characteristics of the barley seeds

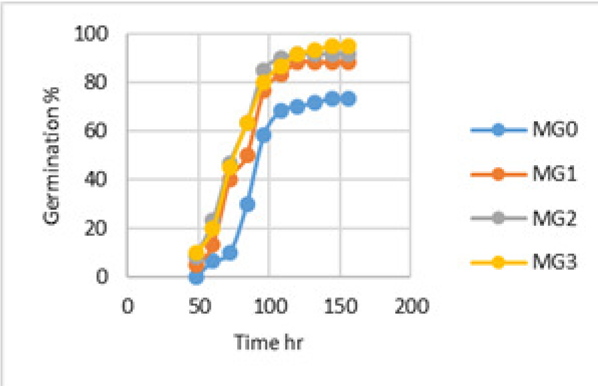

Fig. 1 : Mean values germination percentage of barley seeds as affected by magnetic field exposure treatments for 0 h (MG0); 2 h (MG1); 4 h (MG2) and 6 h (MG3), (MG0) as control.

exposure. For example, Lazim and Ramadhan (2019) have reported an increase in some germination characteristics, such as a final germination percentage, speed germination, germination rate index, and germination index, when exposing the seeds of wheat for 1, 2 and 3 hours to a static magnetic field of 125 mT. An increase in the percentage germination and rate of germination, and decreases in the mean germination time have been recorded in treating cereal seeds with 125 mT SMF (Martinez *et al*, 2017). Moreover, similar observations have been reported in sunflowers (Vashisth and Nagarajan, 2010) and lettuce seeds (Mousavizadeh *et al*, 2013).

Table 1. Effect of various static magnetic field exposure times on some germination characteristics of barley seeds.

Exposure time	Seed Germination Characteristics				
	FGB %	S.G seed day^{-1}	MGT day	GRI % day^{-1}	GI
Control	73.33	3.67	4.1	18.36	57.33
2 hour	88.33	5.13	3.65	26.78	77.33
4 hour	91.67	5.57	3.47	27.86	83
6 hour	95	5.66	3.61	28.31	84
L.S.D.	14.12	1.384	N.S	7.09	18.12

L.S.D0.05= Least significant difference in probability 5%; N.S=Non-significance; FGB: final germination percentage; SG: speed germination; MGT: mean germination time; GRI germination rate index and GI: germination index.

studied, except the mean germination time. The highest values of germination percentage (95%), speed germination (5.66 seed day^{-1}), germination rate index (28.31% day^{-1}) and germination index (84) were recorded at the 6-hour exposure time compared with untreated seeds, with an increase of 29.55, 54.22, 54.19, and 46.52%, respectively (Table 1). While, the greatest reductions were found in the mean germination time for all treatment exposure time compared with untreated seeds, in spite had not observed a significant difference. However, the MGT for the three exposure treatments had been more than three days compared with untreated seeds (4.1 days), where a lower MGT indicates a faster seed germination rate. These results finally show that the control treatment had delayed germination compared to other seed treatments. Some germination characteristics of our results may be in agreement with the data of sorghum seeds, which was recorded by Lazim and Nasur (2017), whose authors observed an increase in germination percentage and speed germination in the treatment of the magnetic field of 125 mT at 6 hours exposure time. Also, our results could be identified with those some other reports, which recorded an increase in germination traits of various crop seeds that have been exposed to several MFs and at different times of

The working mechanisms of a magnetically treated seed have remained unknown until now. However, many mechanisms theories have been proposed, such as enzyme activity, ion channel properties and reactive oxygen species (ROS) production. Some authors suggested that the activities of enzymes, such as amylase, dehydrogenase, and protease in magnetic treatment seeds, such as corn (Torres *et al*, 2018), soybean (Kataria *et al*, 2015), cumin (Samani *et al*, 2013) and sunflower (Vashisth and Nagarajan, 2010) seeds may be responsible for the increase in germination. Moreover, an increase in peroxidase activity has been recorded in treating lettuce seed with the best exposure times at 1-6 hours (Mousavizadeh *et al*, 2013). Another hypothesis cleared that the magnetic field could influence the structure of cell membranes and increases their permeability and ion transport through the ion channels (Shine *et al*, 2012). Which then may affect a variation in the osmotic pressure to cause changes in cellular tissues to lead to an increase in water absorption and ionic current in seeds (Radhakrishnan and Kumari, 2013; Socorro and Garca, 2012). These results could be relevant to explain biochemical and physiological process changes found in post-germination parameters, which can lead to quick germination seeds (Podlesna *et al*, 2019). Further possible

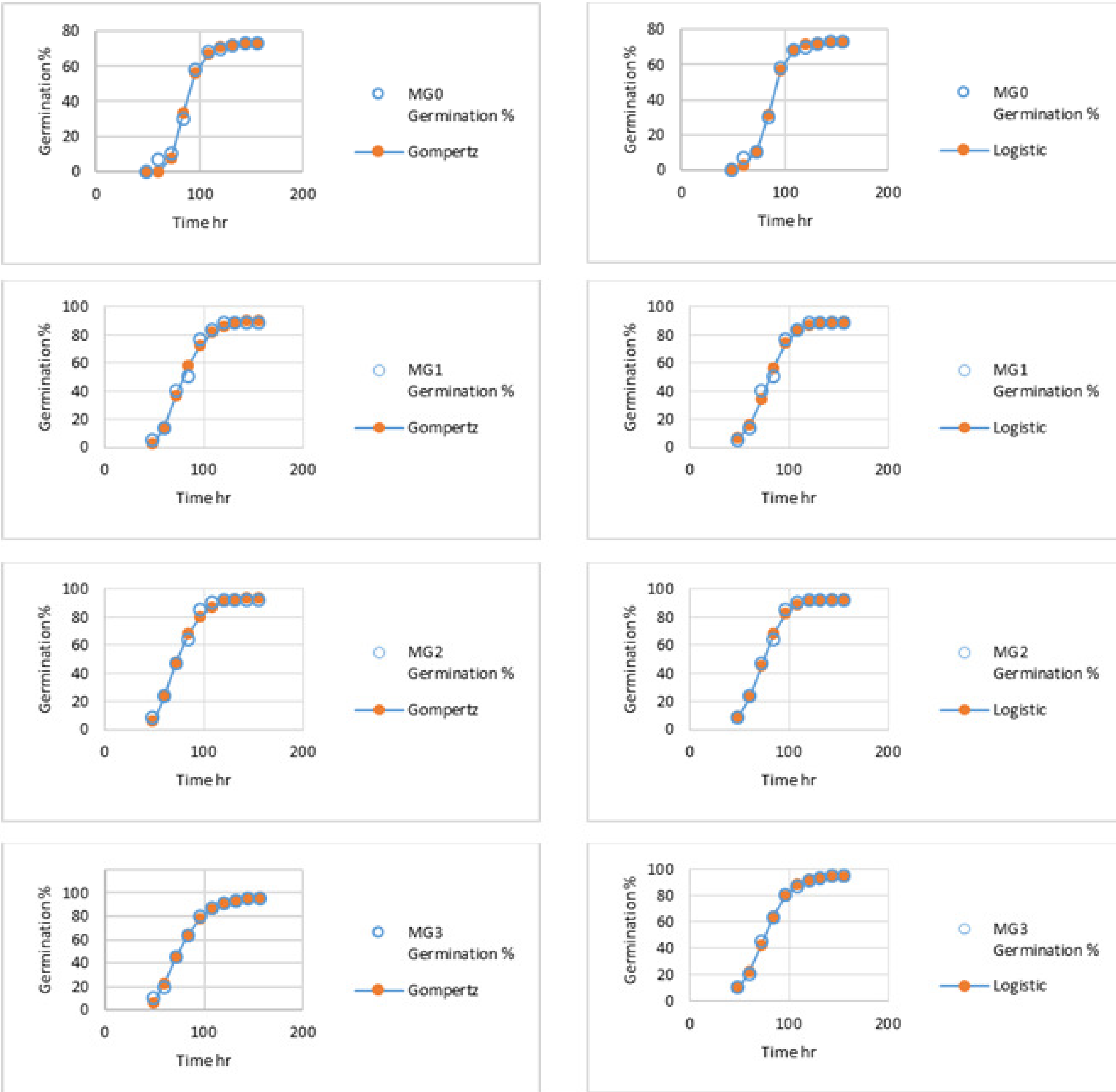

Fig. 2 : The experimental germination curves of barley seeds as a function of the germination time for various times of magnetic field exposure. Open symbols (o): Experimental-data; Solid symbols (●): Model- data. Gompertz and Logistic equations have fitted to the mean values of 3 replications of 20 seeds each per treatment. Exposure times: 0 (MG0), 2 h (MG1), 4 h (MG2), and 6 h (MG3), MG0 as control.

theory shows that a biochemical parameter mechanism has associated with germination and seedling growth under magnetically treated seeds, which has concerning an increased production of reactive oxygen species (ROS) by cell wall peroxidase (Shine *et al*, 2012).

Fig. 1 shows the germination process curves of the magnetically treated seeds, which compared to the untreated seeds (control). Points on the curves represent the percentage of the actual number of seeds germinated during the magnetic exposure treatments obtained from the counting daily at 12-hour intervals. The germinating seed began to emerge after 48h of beginning sowing up to 120 hours, reaching 88.33, 91.67 and 95 percent of exposure periods 2, 4, and 6 hours, respectively. While control seed germination began after 60 hours of sowing, reaching 73.33 at 156 hours. These best results might be in agreement with the results of several studies of various crop seeds exposed to different exposure times of MFs (Lazim and Ramadhan, 2020b and Martinez *et al*, 2000).

Table 2 : Estimated parameters, MSE and R^2 values of barley seed germination using Logistic model for a magnetic field.

Treatment			Inflection point					
	A (h^{-1})	B	C	V_{max} (%h^{-1})	T_{inf} (h)	G_{inf} (%)	MSE	R^2
MG0	0.10	58349.47	72.58	1.81	84.42	36.29	1.588	0.86
MG1	0.09	823	89.29	2	74.59	44.64	10.795	0.86
MG2	0.09	610.06	92.63	2.07	71.26	46.31	3.524	0.81
MG3	0.08	388.5	94.42	1.88	74.53	47.21	1.787	0.85

A, B and C are model parameters, R^2: coefficient of determination, MSE: mean square error.

Table 3 : Estimated parameters, MSE and R^2 values of barley seed germination using Gompertz model for a magnetic field.

Treatment			Inflection point					
	A (h^{-1})	B	C (%)	V_{max} (%h^{-1})	T_{inf} (h)	G_{inf} (%)	MSE	R^2
MG0	0.07	1197.07	73.56	1.89	78.75	27.07	5.180	0.87
MG1	0.06	59.28	91.07	2.01	68.04	33.51	11.866	0.86
MG2	0.06	49.98	94.22	2.07	65.19	34.67	6.930	0.82
MG3	0.05	35.25	96.78	1.78	71.25	35.61	2.777	0.86

A, B and C are model parameters, R^2: coefficient of determination, MSE: mean square error.

Gompertz and Logistic function analysis of germination

Fig. 2 shows the cumulative germination of barley seed growth curves for different magnetic exposure times using the Logistic and Gompertz equations, 6 and 7, respectively. In each curve, the open symbols represent the values obtained from measurements, while the solid symbols represent the values of Logistic and Gompertz functions calculated. Exposure times are: 0h (MG0), 2h (MG1), 4h (MG2) and 6h (MG3).

Tables 2 and 3 summarize the results of Gompertz and Logistic equations growth curve fitting to cumulative germination data, respectively in each magnetic treatment. The asymptotic value of the cumulative percentage of germinated barley seeds has obtained from the fit curve of Gompertz and Logistic models, Where the 6-hour exposure time gave the highest value, 96.78% and 94.42%, respectively. The MG3 treated seed for the Logistic equation produced the highest value germination percentage at the inflection point (47.21%). While the Gompertz equation, the lowest value was found in untreated seeds (MG0) (27.07%). Furthermore, the higher time at the point of inflection has been found at untreated seeds MG0 for Logistic (84.42 h) and the lowest time has been found at MG2 treatment for Gompertz (65.19 h). Also, results in tables 2 and 3 have given the maximum germination rates, which reached 2.07% h^{-1} for seeds exposed to 4 hours for both Logistic and Gompertz equations. Besides, results from the growth curve fitting show that, as compared to the Gom function, the Log function showed the lowest MSE in all magnetic exposure periods (Tables 2 and 3). It has concluded that the Logistic function has shown more fit for the growth curve in MG treatment as compared with Gompertz functions. According to our knowledge, there are no previous studies on magnetic treatments of barley seed that investigated their mathematical expressions of cumulative seed germination kinetics. Therefore, it is not possible to compare our results with other studies. Therefore, it is not possible to compare our results with other studies.

CONCLUSION

According to the results obtained from the magnetic treated barley seed, I concluded that the exposure time of 6 h gave the best values for all seed germination characteristics. The highest value of asymptotic germination barley seeds was observed using the Gompertz growth curve model at 6 h exposure times with magnetic treatment. Moreover, the highest percentage germination value of the point-inflection of the curve has been observed for 6 h in the Logistic model with magnetic treatments. The rate of highest germination on growth curves has reported within the both Gompertz and Logistic models at exposure times 4 h. The lowest values for MSE in the magnetic seed treatments have been recorded in Logistic growth curve models compared to Gompertz models. In summary, as compared to the Gompertz model, the Logistic curve model has shown a better fit under magnetic treatments.

Conflict of interest : Authors declare that there is no conflict of interests.

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